National Aeronautics and Space Administration

FROM QUESTIONS TO DISCOVERIES

Exploring with Light and Color

Student Workbook

Name: ________________________________

"From the time of our birth, it is our instinct to explore.

To map the lands, we must explore.
To chart the seas, we must explore.
To make new discoveries, we must explore."

—*Neil Armstrong*

exploration

Exploration: From Questions to Discoveries

Use this student workbook to keep track
of your findings and discoveries.

My school: ___________________________________

My grade: ____________________________________

These activities developed by Space Telescope Science Institute 2008.
For more information, please contact: **amazing-space@stsci.edu**
or find more resources online at **http://amazing-space.stsci.edu**

Contents

Light Exploration:

What is the relationship between **light** and **exploration**?

Activity 1: Exploring Visible Light

Student Directions

1. Observe the prism demonstration conducted by your teacher.

2. Describe and explain what you see inside the box.

3. Think about if you have seen something similar to this, or think about what you know about light.

Activity 2: Exploring Filters

Student Directions

1. Look through the diffraction glasses and observe the light bulb when it is turned on.

2. Be sure not to stand too close to the light or touch it when it is turned on.

3. Describe and explain what you see. Is what you see similar to, and different from, what you observed during the prism demonstration?

4. Think about what a filter does. Predict how you think the red and blue filters will change the way the light looks.

5. While looking at the light with the diffraction glasses, pass the blue filter sheet in front of your glasses. Describe what you see. How has the appearance of the light changed? How does this compare with your predictions?

6. Do the same thing with the red filter sheet. Describe what you see. How has the appearance of the light changed? How does this compare with your predictions?

7. Compare the appearance of the light with the blue filter with the appearance of the light with the red filter. Explain how filters work, or how they change the way the light looks.

8. Predict what you would see if you used a green filter.

Activity 3: Exploring Emission Spectra

Student Directions

– CAUTION: HIGH VOLTAGE –
DO NOT TOUCH THE POWER SUPPLIES OR TUBES

1. Observe each gas tube after your teacher turns on each power supply. Describe what you see.

2. Observe each gas tube again while wearing the diffraction glasses. Describe what you see.

3. Use crayons or colored pencils to record what you see for each gas tube while wearing the diffraction glasses. Do this on page 5 of your student workbook.

4. Try to record line color, size, and spacing as accurately as possible. Also, be sure to label each drawing with the name of the gas tube it goes with.

5. Compare your drawings. Do they all look the same? Explain.

6. Explain what this can tell you about objects in the universe.

Sketch pad

Draw what you see.

Activity 4: How light is used as a Tool

Student Directions

1. Examine the Electromagnetic Spectrum Poster. The large image on the poster shows the center of the Whirlpool Galaxy (M51). The small images across the bottom of the poster show the Whirlpool Galaxy as it appears in different types of light.

2. Use the small images to identify a feature that is visible in all or several types of light. Explain what this means.

3. Use the small images to identify a feature that is visible in only one or a few types of light. Explain what this means.

4. Explain why light is an important tool for studying and learning about the universe.

Questions

My questions about light and exploration:

My data notes:

New thing(s) I learned during this activity:

If I had more time with this activity what other things would I like to learn about?

Myths vs. realities

Myth 1: Visible light is the only type of light.

Reality: Visible light is just a tiny slice of radiation that makes up the electromagnetic spectrum. In order from lowest energy to highest energy, and longest wavelength to shortest wavelength, the radiation types are: radio, microwave, infrared, visible light, ultraviolet, X-rays, and gamma rays.

Myth 2: All radiation is harmful.

Reality: All radiation is not harmful. Light is a form of radiation. All parts of the electromagnetic spectrum are considered radiation, but only X-rays and gamma rays are made up of harmful, ionizing radiation. Ionizing radiation is dangerous because it can penetrate body tissues and cause cell damage. Radiation with wavelengths equal to or longer than visible light (radio, infrared, and visible light) is considered harmless.

Myth 3: The primary colors of light are identical to the primary colors of pigments.

Reality: The primary colors of light are red, green, and blue, while the primary colors of pigments are red, yellow, and blue. When combined, the primary colors of pigments produce a black pigment, while the primary colors of light produce white light.

continued...

Myths vs. realities continued

Myth 4: Red objects in space are hot; blue objects are cool.

Reality: In astronomy, the color of an object does not always signify its temperature. An object's color can mean many different things, including its distance from Earth, its temperature, and its chemical makeup.

Myth 5: Filters change the color of light.

Reality: Filters don't change the color of light, but they do allow only certain colors of light to pass through, and block the others.

Questions & Answers

1. What is the electromagnetic spectrum?

The electromagnetic spectrum consists of all the different wavelengths of electromagnetic radiation, including light, radio waves, and X-rays (see chart below). It is a continuum of wavelengths from zero to infinity. We name regions of the spectrum rather arbitrarily, but the names give us a general sense of the energy; for example, ultraviolet light has shorter wavelengths than radio light. The only region in the entire electromagnetic spectrum that our eyes are sensitive to is the visible region.

- **Gamma rays** have the shortest wavelengths, of less than 0.01 nanometers (about the size of an atomic nucleus). This is the highest frequency and most energetic region of the electromagnetic spectrum. Gamma rays can result from nuclear reactions taking place in objects such as pulsars, quasars, and black holes.

- **X-rays** range in wavelength from 0.01 to 10 nanometers (about the size of an atom). They are generated, for example, by super-heated gas from exploding stars and quasars, where temperatures are near a million to ten million degrees.

- **Ultraviolet** radiation has wavelengths of 10 to 310 nanometers (about the size of a virus). Young, hot stars produce a lot of ultraviolet light and bathe interstellar space with this energetic light.

- **Visible light** covers the range of wavelengths from 400 to 700 nanometers (from the size of a molecule to a protozoan). The Sun emits most of its radiation in the visible range, which our eyes perceive as the colors of the rainbow. Our eyes are sensitive only to this small portion of the electromagnetic spectrum.

continued...

Questions & Answers continued

- **Infrared** wavelengths span from 710 nanometers to 1 millimeter (from the width of a pinpoint to the size of small plant seeds). At a temperature of 37 degrees C, our bodies radiate with a peak intensity near 900 nanometers.

- **Radio** waves are longer than 1 millimeter. Since these are the longest waves, they have the lowest energy and are associated with the lowest temperatures. Radio wavelengths are found everywhere: in the background radiation of the universe, in interstellar clouds, and in the cool remnants of supernova explosions, to name a few. Radio stations use radio wavelengths of electromagnetic radiation to send signals that our radios then translate into sound. These wavelengths are typically a few feet long in the FM band and up to 300 yards or more in the AM band. Radio stations transmit electromagnetic radiation, not sound. The radio station encodes a pattern on the electromagnetic radiation it transmits, and then our radios receive the electromagnetic radiation, decode the pattern and translate the pattern into sound.

New instrumentation and computer techniques of the late 20th century allow scientists to measure the universe in many regions of the electromagnetic spectrum. We build devices that are sensitive to the light that our eyes cannot see. Then, so that we can "see" these regions of the electromagnetic spectrum, computer image-processing techniques assign arbitrary color values to the light.

2. What information can light reveal about the stars?

Electromagnetic radiation, or light, is a form of energy. Visible light is a narrow range of wavelengths of the electromagnetic spectrum. By measuring the wavelength or frequency of light coming from objects in the universe, we can learn something about their nature. Since we are not able to travel to a star or take samples from a galaxy, we must depend on electromagnetic radiation to carry information to us from distant objects in space.

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Questions & Answers continued

The human eye is sensitive to a very small range of wavelengths called visible light. However, most objects in the universe radiate at wavelengths that our eyes cannot see. Astronomers use telescopes with detection devices that are sensitive to wavelengths other than visible light. This allows them to study objects that emit this radiation, which would otherwise be invisible to us. Computer techniques then code the light into arbitrary colors that we can see.

The Hubble Space Telescope is able to measure wavelengths from about 0.1150 to 2 micrometers, a range that covers more than just visible light. These measurements of electromagnetic radiation enable astronomers to determine certain physical characteristics of objects, such as their temperature, composition, and velocity.

3. Why does Hubble need to take images using non-visible light?

The human eye is sensitive to a very small range of wavelengths called visible light. However, many celestial objects in the universe radiate at wavelengths that our eyes cannot see… and each type of radiation provides clues as to the nature of the object in question. Astronomers study celestial objects with detection devices that are sensitive to wavelengths other than visible light and then use computer techniques that code the light into colors that we can see.

Able to measure wavelengths from about 115 nanometers to 2500 nanometers, the Hubble Space Telescope looks at the energy that is not only visible, but also infrared and ultraviolet. These measurements better enable astronomers to determine physical characteristics of objects, such as their temperature, composition, and velocity.

4. Why do astronomers want to detect infrared light?

Unlike visible light, infrared light isn't absorbed or scattered by the clouds of gas and dust found abundantly in the universe. Therefore, astronomers are able to see through the dust around newly forming stars and measure the properties of the disks of dust particles believed

continued...

Questions & Answers continued

to give birth to planetary systems around these stars. They are able to peer into the dusty centers of galaxies, including our Milky Way, to study quasars and other exotic objects.

Astronomers are able to observe some of the universe's oldest and most distant objects, observations that could someday answer questions about the size, structure, and future of the universe.

5. Why do scientists need filters, and how do they work?

Different wavelengths of light provide scientists with different information about the objects they are studying. For instance, infrared light can reveal details about objects shrouded in dust. Infrared light emitted by an object will pass through dust — unlike visible light, which is scattered. In contrast, ultraviolet light can reveal details about the stellar wind around stars. (When talking about our sun, this is called the solar wind.) Astronomers have ways of breaking light into a spectrum, which reveals a lot of information (including properties of the source of the light, the material through which the light passes, or the material off of which the light reflects).

However, sometimes scientists want to capture specific ranges of wavelengths of light, so they use a filter. A filter will allow only light within a small range of wavelengths to pass through. When the Hubble Space Telescope takes an image using a filter, that image shows only the varying intensity of light in that small range. In making color pictures, scientists usually use a red filter, a green filter, and a blue filter (the red filter allows light only in the red range to enter, etc.). By combining these images scientists can create full-color pictures.

6. Why choose red, green, and blue as the assigned colors for images?

The colors red, green, and blue are chosen because they are the primary colors of light. By combining these colors of light, white light is produced. Combinations of two of these colors produce other familiar colors:
blue + green = cyan, red + blue = magenta, and red + green = yellow.

Galaxy Exploration:

How is light used to explore the **universe**?

Activity 1: Exploring the Hubble Ultra Deep Field (HUDF)

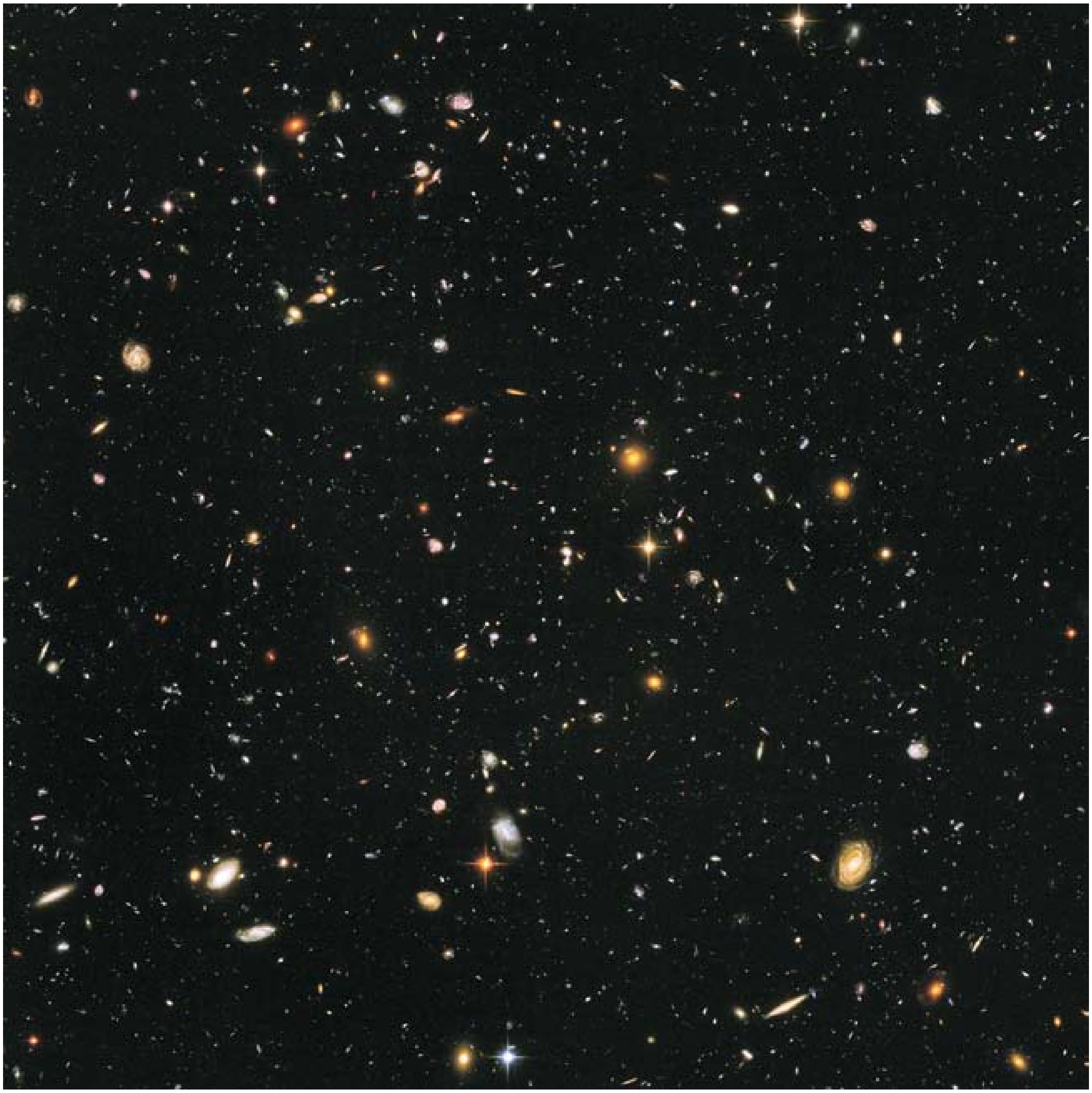
Student Directions

1. Examine the HUDF image provided on the next page.

2. What questions do you have about this image and the objects in it? Think of as many questions as you can.

3. Be prepared to share your questions with the class.

The Hubble Ultra Deep Field



Activity 2: Classifying Deep Field Objects

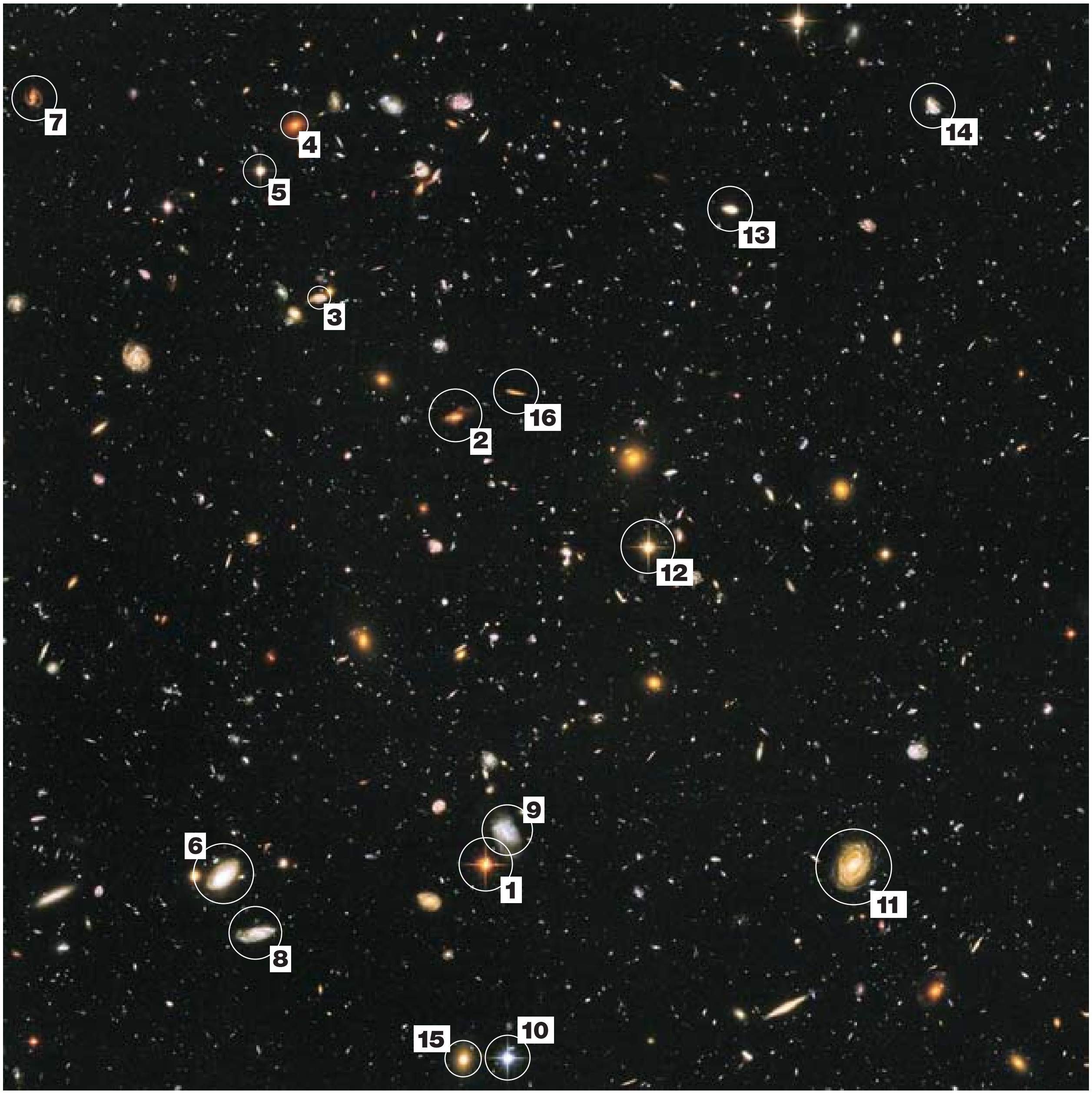
Student Directions

1. Examine the HUDF image provided on the next page. Be sure to pay special attention to the numbered objects. Use the hand lens provided by your teacher to help you see the objects more closely.

2. Describe the numbered objects. Tell what you think the numbered objects are and why.

3. Think about how you would classify the numbered objects into groups. Create and label your groups in the space provided on page 19.

The Hubble Ultra Deep Field



My classification system

Activity 3: A Team Classification System

Student Directions

1. The HUDF image contains a combination of stars and galaxies. Identify the numbered objects that you think are stars. Identify the numbered objects that you think are galaxies.

2. There are three main types of galaxies: spiral, elliptical, and irregular. Identify an example of each type in the HUDF. Use the information on the next page to help you.

3. Preview the team classification chart on page 22.

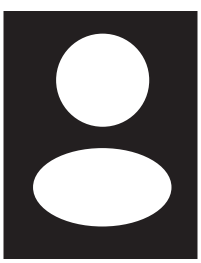
4. Share your grouping strategy with your team. Then work with your team to group the numbered objects in the HUDF image by completing the team classification chart on page 22.

5. Be prepared to select a group reporter to share your team's results with the class.

Classifying and Identifying Objects

STARS:
Stars are massive, gaseous bodies that undergo nuclear reactions and emit light. Stars do not really have spikes, even though they appear that way in the Hubble Ultra Deep Field. These spikes are caused by scattered light within the telescope's optical assembly.

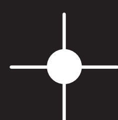
SPIRAL GALAXIES:
Spiral galaxies have two or more "arms" winding out from a central disk. When viewed from the side, a spiral galaxy resembles a fried egg. Some of the long, narrow objects in the Hubble Ultra Deep Field may be side views of spiral galaxies.



ELLIPTICAL GALAXIES:
Elliptical galaxies come in a variety of shapes ranging from round to flattened. Elliptical galaxies have a smooth, featureless appearance and appear basically the same from any angle.

IRREGULAR GALAXIES:
Irregular galaxies have stars, dust, and gas scattered in random patches.

Astronomers' Chart

		Object Shape				
						**IRREGULAR**
Object Color	**BLUE**					
	WHITE					
	YELLOW					
	RED					

Activity 4: Understanding the Scientific Process

Student Directions

1. Examine the Astronomers' Chart provided by your teacher.

2. Compare the astronomers' results to your team's results. Discuss with your team any similarities and/or differences between the two sets of results.

3. Explain why your results may be different from the astronomers' results.

4. Explain why it may be difficult for scientists to always agree.

Questions

My questions about light and the universe:

My data notes:

What new thing(s) I learned during this activity:

If I had more time with this activity what other things would I like to learn about?

Myths vs. realities: Galaxies

Myth 1: Most galaxies are easily viewed with the naked eye.

Reality: Most galaxies are so far away that people can view them only with the help of telescopes. Only three galaxies can be seen with the unaided eye: the Andromeda Galaxy and the Large and Small Magellanic Clouds. These galaxies appear as cloudy patches in the sky. Other galaxies appear as fuzzy spots in the sky when viewed with small telescopes.

Myth 2: All galaxies are the same.

Reality: The shapes of galaxies vary – some are elliptical, others are spiral, and still others have no definite shape. Galaxies differ in color, composition, orientation, age, size, the number of stars within them, and their distance from Earth.

Myth 3: Galaxies are composed of stuff that is different from stars.

Reality: Galaxies are large collections of stars, gas, and dust held together by their gravitational attraction.

Myth 4: Galaxies are all the same size.

Reality: The size of a galaxy depends on the number of stars in the galaxy. The smallest galaxies may contain only a few hundred thousand stars, while the largest galaxies have thousands of billions of stars.

continued...

Myths vs. Reality: Galaxies continued

Myth 5: Galaxies are all the same color.

Reality: The color of a galaxy depends on the color of the stars within the galaxy. Some young stars, for example, are very bright blue. A young galaxy therefore appears blue. Old stars are red. A galaxy containing mostly old stars appears red.

Myth 6: Galaxies are static, remaining unchanged with time.

Reality: In fact, galaxies are dynamic and change over millions of years. Stars are born and die in galaxies. A galaxy also can interact with another galaxy, which alters both galaxies' shapes.

Myth 7: You can judge the distance of a galaxy based on its size.

Reality: The size a galaxy appears to be to an observer depends on how many stars are in it and how far away it is. Two galaxies may appear to be the same size. One of them, however, may be a small galaxy close to Earth and the other a large galaxy that is much farther away.

Questions & Answers: Galaxies

1. **What is a galaxy?**

   A galaxy is an enormous collection of a few million to trillions of stars, gas, and dust held together by gravity. Galaxies can be several thousand to hundreds of thousands of light-years across.

2. **What is the name of our galaxy?**

   The name of our galaxy is the Milky Way. All of the stars that you see at night and our Sun belong to the Milky Way. When you go outside in the country on a dark night and look up, you will see a milky, misty-looking band stretching across the sky. When you look at this band, you are looking into the densest parts of the Milky Way: the disk and the bulge.

3. **Where is Earth in the Milky Way galaxy?**

   Our solar system is in a spiral arm called the Orion Arm, and is about two-thirds of the way from the center of our galaxy to the edge of the starlight. Earth is the third planet from the Sun in our solar system of eight planets.

4. **What is the closest galaxy like our own, and how far away is it?**

   The closest spiral galaxy is Andromeda, a galaxy much like our own Milky Way. It is 2.2 million light-years away from us. Andromeda is approaching our galaxy at a rate of 670,000 miles per hour. Five billion years from now it may even collide with our Milky Way galaxy.

5. **Why do we study galaxies?**

   By studying other galaxies, astronomers learn more about the Milky Way, the galaxy that contains our solar system. Answers to such questions as "Do all galaxies have the same shape?," "Are all galaxies the same size?," "Do they all have the same number of stars?," and "How and when did galaxies form?" help astronomers learn about the

continued...

Questions & Answers: Galaxies continued

history of the universe. Galaxies are visible to vast distances, and trace the structure of the visible universe with their collections of billions of stars, gas, and dust.

6. **How are galaxies classified? What do they look like?**

   Edwin Hubble classified galaxies into four major types: spiral, barred spiral, elliptical, and irregular. Most galaxies are spirals, barred spirals, or ellipticals.

   A spiral galaxy consists of a flattened disk containing spiral (pinwheel-shaped) arms, a bulge at its center, and a halo. Spiral galaxies have a variety of shapes, and they are classified according to the size of the bulge and the tightness and appearance of the arms. The spiral arms, which wrap around the bulge, contain many young blue stars and lots of gas and dust. Stars in the bulge tend to be older and redder. Yellow stars like our Sun are found throughout the disk of a spiral galaxy. These galaxies rotate somewhat like a hurricane or a whirlpool.

   A barred spiral galaxy is a spiral that has a bar-shaped collection of stars running across its center.

   An elliptical galaxy does not have a disk or arms; rather, it is characterized by a smooth, ball-shaped appearance. Ellipticals contain old stars and possess little gas or dust. They are classified by the shape of the ball, which can range from round to oval (baseball-shaped to football-shaped). The smallest elliptical galaxies (called dwarf ellipticals) are probably the most common type of galaxy in the nearby universe. In contrast to spirals, the stars in ellipticals do not revolve around the center in an organized way. The stars move on randomly-oriented orbits within the galaxy like a swarm of bees.

   An irregular galaxy is neither spiral nor elliptical. Irregular galaxies tend to be smaller objects without definite shape, and they typically have very hot newer stars mixed in with lots of gas and dust. These galaxies often have active regions of star formation. Sometimes their

continued...

Questions & Answers: Galaxies continued

irregular shape is the result of interactions or collisions between galaxies. Observations such as the Hubble Deep Fields show that irregular galaxies were more common in the distant (early) universe.

7. Who is Edwin P. Hubble and what has he to do with galaxies?

Edwin P. Hubble revolutionized cosmology by proving that galaxies are indeed "island universes" beyond our Milky Way galaxy. His greatest discovery was in 1929, when he identified the relationship between a galaxy's distance and the speed with which it is moving. The farther a galaxy is from Earth, the faster it is moving away from us. This is known as Hubble's Law.

Edwin Powell Hubble was born in Kentucky, where he grew up observing the habits of birds and animals. In 1910 he received his undergraduate degree from the University of Chicago and studied law under a Rhodes Scholarship at Oxford University. Later he changed his mind and completed a Ph.D. in astronomy at Chicago's Yerkes Observatory in 1917. He had several other interests, and for a while he thought of becoming a professional boxer. He also enjoyed basketball, and even answered a call in World War I to serve in the infantry.

Hubble once said that he "chucked the law for astronomy," knowing that even if he was second-rate or third-rate, it was astronomy that mattered.

8. Why do we study distant galaxies, if they are faint and hard to observe?

When we study astronomical objects, we are actually looking back in time. Light from the Sun takes eight minutes to reach Earth. The light we see today from the next nearest star was emitted about four years ago. Light from the nearest galaxy like our own, Andromeda, takes over 2 million years to reach us. That is, we see Andromeda as it appeared more than 2 million years ago. Observations of distant galaxies show us what the universe looked like at an earlier time in the history of the universe. By studying the properties of galaxies at different epochs, we can map the evolution of the universe.

continued...

Questions & Answers: Galaxies continued

9. When scientists study these distant galaxies, what do they look at?

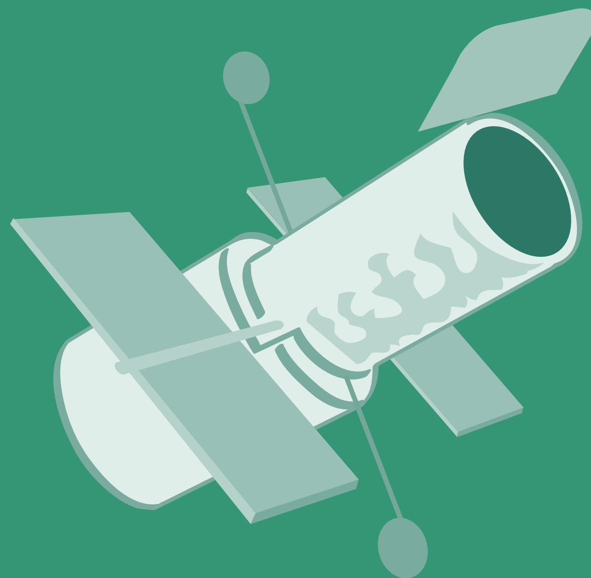
They observe many properties of each galaxy, including size, shape, brightness, color, amount of star formation, and distance from Earth. This information helps astronomers to determine how these structures may have formed and evolved.

10. What is a "deep" field?

In astronomical terms, a deep field is a long-exposure observation taken to view very faint objects. Light from these objects is collected over a large period of time, so the detectors have a chance to gather as much light as possible. Objects can be very far away and appear faint to us due to the vast distances over which the light must travel; and/or objects can lie close to us and be faint because they don't give off much light. So "deep" doesn't necessarily mean far. However, in the case of the Hubble Deep Fields (HDFs) and the Hubble Ultra Deep Field (HUDF), deep does mean far away since the images were taken in areas that we know have few nearby stars.

11. It is hard to see the shapes of some of the galaxies in the HDFs. How do astronomers classify them?

They use the colors of the galaxies. Different types of galaxies tend to be different colors. For example, elliptical galaxies have reddish colors because they are mostly composed of old red stars. Astronomers study the colors of nearby elliptical, spiral, and irregular galaxies and compare these colors to those of the galaxies in the Hubble Deep Fields. Comparing the colors allows them to classify the galaxies.



Exploring Hubble:

About the **Hubble** Space Telescope

Myths vs. realities: Hubble Space Telescope

Myth 1: The Hubble Space Telescope is a manned satellite, with astronauts living and conducting research on it as it orbits the Earth.

Reality: The telescope is unmanned and controlled from the Earth. Astronomers request observation time on the telescope and conduct their research on Earth.

Myth 2: The Hubble Space Telescope can only magnify visible space objects.

Reality: The Hubble telescope can magnify objects so that astronomers can see them more clearly. But the telescope also can detect objects that are invisible to the human eye, such as infrared and ultraviolet light.

Myth 3: The Hubble Space Telescope can observe celestial bodies better than other observatories because it is closer to them, or because it travels to the celestial bodies.

Reality: The Hubble Space Telescope orbits the Earth. It produces clearer images than ground-based telescopes because it is above Earth's atmosphere. The Earth's atmosphere distorts our view of objects in space.

Myth 4: The Hubble Space Telescope takes pictures of celestial objects, like taking snapshots with the family camera.

Reality: The Hubble Space Telescope does not use film to take images. The telescope instead takes digital images, which are transmitted to Earth. Scientists, however, do not think of Hubble as a giant digital camera in space, but rather as a scientific instrument that observes objects for analysis. These observations can be converted into pictures, but pictures are not Hubble's primary purpose.

continued...

Myths vs. realities: Hubble Space Telescope continued

Myth 5: The Hubble Space Telescope can take pictures of anything.

Reality: The telescope cannot take pictures of everything in space. For example, pointing it near the Sun or other very bright objects, such as the Earth, could damage the instruments. On one occasion, the telescope snapped pictures of the Moon, but this took much effort since the Moon is very bright and appears to move through the sky more rapidly than other, more distant, objects. The Hubble Space Telescope has also never taken pictures of Mercury because it is too close to the Sun.

Myth 6: NASA has "warp drive" technology.

Reality: Warp drive is an imaginary device used in science fiction. Objects cannot travel faster than the speed of light (300,000 kilometers per second, or 186,000 miles per second).

Myth 7: NASA spacecraft can travel at or near the speed of light.

Reality: Spacecraft travel much slower. For example, the Cassini spacecraft was successfully launched on October 15, 1997, and is expected to reach Saturn in July 2004. The Apollo missions took slightly more than three days to travel from the Earth to the Moon. At the speed of light, it would take about 1 second to reach the Moon and about an hour and fifteen minutes to reach Saturn.

Questions & Answers: Hubble Space Telescope

1. What is the Hubble Space Telescope?

The Hubble Space Telescope is a space-based telescope that was launched in 1990 from the space shuttle Discovery. From its position above Earth's atmosphere, Hubble has expanded our understanding of the universe — and of star birth, star death, galaxy evolution, and black holes in particular.

The telescope's science instruments are the astronomer's eyes to the universe. During Servicing Mission 4, planned for fall 2008, astronauts will boost Hubble's scientific power by installing two state-of-the-art science instruments: the Cosmic Origins Spectrograph (COS) and the Wide Field Camera 3 (WFC3). To make room for the new instruments, astronauts plan to remove the Wide Field and Planetary Camera 2, which was installed aboard Hubble in 1993. Other Hubble science instruments include the Space Telescope Imaging Spectrograph, Near Infrared Camera and Multi-Object Spectrometer, and Advanced Camera for Surveys.

When first launched, Hubble's primary mirror had a minor flaw that made it difficult for the telescope to resolve faint objects. Because the telescope is in low Earth orbit, it can be serviced by a space shuttle; thus, the defect was corrected during the first on-orbit servicing mission. The Hubble Space Telescope is scheduled for one more servicing mission in the fall of 2008.

2. What impact has Hubble had on society?

Not since Galileo turned his telescope toward the sky in 1610 has any event so changed our understanding of the universe as the success of the Hubble Space Telescope. Hubble orbits above Earth's atmosphere, working around the clock to unlock the secrets of the universe. It uses excellent pointing precision, powerful optics, and state-of-the-art instruments to provide stunning views of the universe that cannot be made using ground-based telescopes or other satellites.

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Questions & Answers: Hubble Space Telescope continued

Hubble was originally designed in the 1970s and launched in 1990. Thanks to on-orbit service calls by the space shuttle astronauts, Hubble continues to be a state-of-the-art space telescope.

Hubble's accomplishments are extraordinary. Before Hubble, distances to far-off galaxies were not well known. Questions such as how rapidly the universe is expanding, and for how long, created great controversy. Hubble discoveries have changed all of that.

3. What are some of the science highlights from Hubble?

Hubble has observed various parts of the universe and provided scientists with images that have had an impact on several areas of astronomy. Looking at objects in our own solar system, Hubble provided spectacular views of Comet Shoemaker-Levy 9's collision with Jupiter; delivered the first detailed images of Pluto and its satellite Charon; afforded new understanding of the atmospheres of Uranus and Neptune; revealed stunning views of the northern and southern lights on Jupiter, Saturn, and Ganymede, and revealed the dynamic electrical interactions between Jupiter and its satellite Io.

Moving from planets to stars, the telescope documented in colorful detail the births and deaths of these bright celestial objects. It provided visual proof that pancake-shaped dust disks around young stars are common, and showed for the first time that jets of material rising from embryonic stars emanate from the centers of disks of dust and gas, thus turning what was merely theory into an observed reality. Hubble delivered many stunning pictures of stellar deaths, such as the glowing shrouds surrounding sun-like stars (called planetary nebulae) and the mysterious rings of material around the exploding, massive star called Supernova 1987A.

Hubble also managed to probe the crowded central regions of galaxies, where stars, dust, and gas compete for space, and provided decisive evidence that supermassive black holes – compact "monsters" that gobble up any material that ventures near them – reside in the centers of many galaxies. Most scientists believe that black holes

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Questions & Answers: Hubble Space Telescope continued

are the engines that power quasars, powerful light beacons located more than halfway across the universe. Hubble has surveyed quasars, confirming that nature's brightest "light bulbs" reside in distant galaxies.

Hubble looked back in time by probing the distant cosmos to reveal much smaller and more irregularly shaped galaxies than those astronomers see in our nearby universe. These smaller structures, composed of gas and young stars, may be the building blocks from which the more familiar spiral and elliptical galaxies formed.

In the 1920s, astronomer Edwin Hubble observed that the universe doesn't remain still: it's expanding. Since then, astronomers have debated the rate of expansion (a value called the Hubble constant), an essential ingredient needed to determine the age, size, and fate of the universe. In May 1999, a team of astronomers announced they had obtained a value for the Hubble constant and then determined that the universe is 12 to 14 billion years old.

One of the most dramatic astronomical discoveries of this century came in 1998, when two independent teams using Hubble and other telescopes found strong evidence that the cosmic expansion is accelerating. Hubble teamed up with a fleet of X-ray, gamma-ray, and visible-light observatories in a quest to analyze the sources of gamma-ray bursts. Gamma-ray bursts may represent the most powerful explosions in the universe since the Big Bang. Before 1997, astronomers were stumped: although they had observed more than 2000 "bursts," they couldn't determine whether these fireballs occurred in our galaxy or at remote distances. Hubble images showed unambiguously that the bursts actually reside in far-flung galaxies rife with star formation.

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Questions & Answers: Hubble Space Telescope continued

4. **Interesting facts about the Hubble Space Telescope and astronomy…**

    - Pointing the Hubble Space Telescope and locking onto distant celestial targets is like holding a laser light steady on a dime that is 400 miles away.

    - The Hubble Space Telescope whirls around Earth at a speed of 5 miles per second. If cars moved that fast, a coast-to-coast trip across the continental United States would take only 10 minutes.

    - Each month the orbiting observatory collects enough information to fill 70 complete sets of encyclopedias.

    - Images and data collected by the telescope travel 90,000 miles over satellite and ground links before they reach the Space Telescope Science Institute in Baltimore, Maryland.

    - Engineers designed Hubble with servicing in mind. The telescope is equipped with 31 foot restraints and 225 feet of handrails.

    - The tool chest that astronauts use during servicing missions contains more than 100 tools, including common screwdrivers and wrenches.

Putting it Together:

Data **analysis** and follow-up

Data **analysis** and follow-up

Questions

1. How would you answer the exploration station questions?

   Light Exploration: What is the relationship between light and exploration?

   Galaxy Exploration: How is light used to study and explore the universe?

2. How was light used in a similar way with each activity?

3. How was light used in a different way with each activity?

4. Did anything surprise you about light and how it is used to explore?

5. What was the easiest thing for you to understand?

6. What was something that was more difficult to understand?

7. Who do you think in your everyday world uses light to explore?

8. What else would you like to explore about light?

Team notes for group presentation

Glossary

Barred Spiral Galaxy:

A type of spiral galaxy that has a "bar" of stars and interstellar matter, such as dust and gas, slicing across its center. The Milky Way is thought to be a barred spiral galaxy.

Blue Star:

Blue stars are very hot and young. Sirius (Alpha Canis Majoris) is an example of a blue star.

Color:

The visual perception of light that enables human eyes to differentiate between wavelengths of the visible spectrum, with the longest wavelengths appearing red and the shortest appearing blue or violet.

Constellation:

A geometric pattern of bright stars that appear grouped in the sky, and which are named after gods, heroes, animals, and mythological beings by ancient astronomers.

Data:

Collected acts, statistics, or information about something being observed, investigated or studied.

Disk:

The disk is a pancake-shaped structure composed primarily of young and middle-age stars, with abundant gas and dust. Some old stars are also present. It surrounds the bulge in a spiral galaxy. The disk in the Milky Way is 100,000 light-years across and 2,000 light-years thick.

Electromagnetic Spectrum:

The entire range of wavelengths of electromagnetic radiation, including radio waves, microwaves, infrared light, visible light, ultraviolet light, X-rays, and gamma rays.

Elliptical Galaxy:

A galaxy that appears spherical or football-shaped. Elliptical galaxies are comprised mostly of old stars and contain very little dust and "cool" gas that can form stars.

Emit:

To send out or give off. The sun emits radiation, some of which we can feel as heat and some of which we can see as light.

Gamma Rays:

The part of the electromagnetic spectrum with the highest energy; also called gamma radiation. Gamma rays can cause serious damage when absorbed by living cells.

Hubble Space Telescope:

An automated telescope that orbits above Earth's atmosphere and is operated jointly by the National Aeronautics and Space Administration and the European Space Agency. Its primary mirror is 2.4 meters (94.5 inches) wide. The telescope contains an array of instruments capable of carrying out a variety of high-quality astronomical observations in ultraviolet, optical, and infrared wavelengths.

Image:

The appearance of an object, as is produced by reflection from a mirror or refraction by a lens.

Infrared (IR) Light:

The part of the electromagnetic spectrum that has slightly lower energy than visible light, but is not visible to the human eye. Just as there are low-pitched sounds that cannot be heard, there is low-energy light that cannot be seen. Infrared light can be detected as the heat from warm–blooded animals.

Irregular Galaxy:

A galaxy that appears disorganized and disordered, without a distinct spiral or elliptical shape. Irregular galaxies are usually rich in interstellar matter, such as dust and gas. The Large and Small Magellanic Clouds are examples of nearby irregular galaxies.

Light-Year:

The distance traveled by light in a full year, equal to some 10 trillion kilometers (or about 6 trillion miles).

Milky Way:

The specific galaxy to which the Sun belongs, so named because most of its visible stars appear overhead on a clear, dark night as a milky band of light extending across the sky. The Milky Way is a spiral galaxy.

Observation:

In science, an observation is a fact or occurrence that is noted and recorded. The Hubble Space Telescope is a tool astronomers use to make observations of celestial objects.

Orbit:

The act of traveling around a celestial body; or the path followed by an object moving in the gravitational field of a celestial body. For example, the planets travel around, or orbit, the Sun because the Sun's gravitational field keeps them in their paths, or orbits.

Radiation:

The process by which electromagnetic energy moves through space as vibrations in electric and magnetic fields. This term also refers to radiant energy and other forms of electromagnetic radiation, such as gamma rays and X-rays.

Radio Waves:

The part of the electromagnetic spectrum with the lowest energy. Radio waves are the easiest way to communicate information through the atmosphere or outer space.

Red Star:

These are old stars because they have a cooler temperature and a red color. Betelgeuse (Alpha Orionis) is an example of a red star.

Reflection:

Reflection occurs when light changes direction as a result of "bouncing off" a surface like a mirror.

Refraction

Refraction is the bending of light as it passes from one substance to another. Here, the light ray passes from air to glass and back to air. The bending is caused by the differences in density between the two substances.

Satellite:

A man-made object that orbits Earth, the Moon, or another celestial object.

Spiral Arms:

Spiral arms are waves that develop in the disk of a spiral galaxy. They are like the ripples that appear on a pond after tossing a stone into it. Spiral arms contain blue and luminous new stars that are born there. They make the spiral pattern visible.

Spiral Galaxy:

A galaxy made up of a disk, spiral arms, and a bulge at its center. The size of the disk and the bulge vary. The galaxy is composed of a mixture of old and young stars as well as loose interstellar matter.

Star:

A huge ball of gas held together by gravity. The central core of a star is extremely hot and produces energy. Some of this energy is released as visible light, which makes the star glow. Stars come in different sizes, colors, and temperatures. Our Sun, the center of our solar system, is a yellow star of average temperature and size.

Ultraviolet (UV) Light:

The part of the electromagnetic spectrum that has slightly higher energy than visible light, but is not visible to the human eye. Just as there are high-pitched sounds that cannot be heard, there is high-energy light that cannot be seen. Too much exposure to ultraviolet light causes sunburns.

Visible Light:

The part of the electromagnetic spectrum that human eyes can detect; also known as the visible spectrum. The colors of the rainbow make up visible light. Blue light has more energy than red light.

X-Rays:

The part of the electromagnetic spectrum with energy between ultraviolet light and gamma rays. X-rays are used in medicine to detect broken bones and cavities in teeth. Astronomers can detect X-rays from exploding stars and black holes.

Yellow Star:

These stars are middle-aged and not extremely cool nor hot for a star. Earth's Sun is an example of a yellow star.